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Infrastructure and human capital development: an empirical analysis

Chinwendu Benedette Onugha[1], Abimbola Oluwaseun Oladipo[2]
[1,2]Department of Economics, Nnamdi Azikiwe University, Nigeria
Email: bc.onugha@unizik.edu.ng; oa.oladipo@unizik.edu.ng

ABSTRAK

Selama bertahun-tahun, Nigeria berada di peringkat rendah dalam hal pengembangan modal manusia, dan hal ini sebagian besar disebabkan oleh infrastruktur yang tidak memadai yang dibutuhkan untuk perbaikan. Sehubungan dengan hal tersebut, studi ini secara empiris meneliti dampak infrastruktur terhadap pengembangan modal manusia di Nigeria menggunakan data yang bersumber dari Indikator Pembangunan Bank Dunia. Data tersebut mencakup periode 1999 hingga 2022, dan metode yang digunakan untuk analisis adalah mekanisme koreksi kesalahan vektor (VECM). Berdasarkan temuan, akses air dan pendapatan pajak memiliki dampak positif tetapi tidak signifikan terhadap HDI, sedangkan akses internet dan pertumbuhan penduduk memiliki dampak positif yang signifikan. Sebaliknya, akses listrik memiliki dampak negatif dan tidak signifikan terhadap pengembangan modal manusia di Nigeria. Oleh karena itu, studi ini merekomendasikan agar pemerintah menyediakan fasilitas infrastruktur yang memadai untuk kesejahteraan warga negara.

Kata Kunci: infrastruktur; modal manusia; pengembangan

ABSTRACT

For years, Nigeria has ranked low in human capital development, largely due to inadequate infrastructure that needs improvement. In light of this, this study empirically examines the impact of infrastructure on human capital development in Nigeria using data sourced from the World Bank's Development Indicators. The data covers the period 1999 to 2022, and the analysis uses the vector error correction mechanism (VECM) method. Findings indicate that water access and tax revenue have positive but insignificant impacts on HDI, while internet access and population growth have significant positive impacts. Conversely, electricity access has a negative and insignificant impact on human capital development in Nigeria. Therefore, this study recommends that the government provide adequate infrastructure facilities for the well-being of its citizens.

Keyword: infrastructure; human capital; development

Corresponding Author:
Abimbola Oluwaseun Oladipo,
Nnamdi Azikiwe University,
Along Enugu-Onitsha Expressway, Ifite Road, Awka 420110, Anambra State, Nigeria
Email: oa.oladipo@unizik.edu.ng

1. INTRODUCTION

Infrastructure development plays a crucial role in fostering economic growth and improving the standard of living of citizens. It contributes significantly to human development, poverty reduction, and the attainment of the Sustainable Development Goals (SDGs). When adequate infrastructure is provided, numerous opportunities emerge, encouraging individuals to invest in themselves in order to take advantage of these opportunities created by infrastructural advancement (African Development Bank Group, 2018). Investments in electricity, clean water, sanitation, transportation, education, health, and information and communication technology (ICT) are therefore essential for enhancing human capital development. Such investments improve productivity, strengthen businesses, enhance healthcare delivery, and facilitate communication and innovation.

Globally, the Human Development Index (HDI) has shown substantial improvement over the years. According to the United Nations Development Programme (2015), the number of people living in low human development conditions declined significantly between 1990 and 2014. People now live longer, have better access to education, and enjoy improved sanitation and healthcare services. Although these improvements are partly associated with rising income levels, infrastructural development has also been recognized as a major contributing factor because it stimulates investment across different sectors of the economy. In Africa, infrastructure investment accounts for more than half of the recent improvements in economic growth, with many countries recording significant progress in infrastructural expansion between 2016 and 2018 (AfDB, 2018).

In Nigeria, government has increasingly invested in infrastructural facilities such as roads, railways, ports, ICT, and air transportation systems in an effort to stimulate economic growth and human development. Infrastructure constitutes the essential facilities and services necessary for productive economic activities and improved welfare of citizens (Adeshina et al., 2020). Furthermore, investment in ICT has the capacity to improve healthcare delivery, educational accessibility, communication systems, and social advancement (World Bank, 2023). Despite these efforts, Nigeria continues to face severe infrastructural deficits. The World Economic Forum (2018) ranked Nigeria 132nd out of 137 countries in terms of infrastructure quality, indicating a substantial infrastructural gap that requires urgent attention. Although Nigeria possesses abundant natural and oil resources capable of financing infrastructural expansion, the country still struggles with inadequate and poorly maintained infrastructure across major sectors of the economy.

To address these challenges, several policies and initiatives have been introduced by the Nigerian government. These include the Nigeria Infrastructure Fund and the national policy on public-private partnership, which were designed to improve investments in power, transportation, healthcare, water resources, agriculture, and technology (Nigeria Sovereign Investment Authority, 2022; Adeshina et al., 2020). However, despite these initiatives, infrastructural inadequacies remain widespread in Nigeria. The persistent deficiency in infrastructure has negatively affected human development outcomes. Poor ICT infrastructure has contributed to insecurity and educational disruption in many regions, while inadequate access to clean water and sanitation has increased the prevalence of diseases, especially in rural communities (Onikosi-Alliyu & Muhammed, 2025). Consequently, households spend a significant portion of their income on healthcare rather than on self-development and skill acquisition.

Similarly, poor road networks, unstable electricity supply, and inefficient transportation systems discourage both local and foreign investment. This has contributed to high unemployment, low income levels, and reduced opportunities for human capital formation. Individuals without stable income often lack the resources needed to acquire education, technical skills, and productive capabilities necessary for sustainable human development (Ishizuka, 2025). Although the Federal Government introduced the Nigeria Infrastructure Fund to improve infrastructural conditions and support economic development, the country still experiences substantial deficits in electricity, ICT, water supply, sanitation, and transportation infrastructure.

Empirical studies on infrastructure and human development have produced mixed findings across countries and regions. Kusharjanto and Kim (2011) found that electricity positively influenced human development, whereas road infrastructure, education, and water access negatively affected HDI. Nchofoung et al. (2021) reported a negative and insignificant relationship between ICT infrastructure and human development in Africa. Conversely, Okinono et al. (2015) argued that infrastructure remains a significant determinant of human development. These inconsistencies in previous findings indicate the existence of empirical gaps in the literature, particularly within the Nigerian context.

Against this background, this study investigates the impact of infrastructure on human capital development in Nigeria by focusing on access to electricity, access to internet, access to water and sanitation, population growth, and tax revenue. Specifically, the study examines the impact of access to electricity on human development in Nigeria, investigates the extent to which internet accessibility influences human development, and ascertains the effect of access to water and sanitation on human development outcomes in the country.

2. LITERATURE REVIEW

A. Conceptual Issues

1) Infrastructural Development

According to the World Bank (1994), infrastructure development is essential for achieving economic growth and improving the quality of life. Such investments include transportation, power supply, telecommunication, water supply, sanitation, and irrigation facilities. The World Bank (2019) further affirmed that infrastructure plays a vital role in sustaining economic growth. Expanding quality infrastructure investment can support growth objectives by increasing access to basic services, employment opportunities, and markets, while also enhancing private sector productivity.

The literature identifies three major categories of physical infrastructure that are important drivers of economic growth. These include utility infrastructure, proxied by electricity generating capacity in megawatts per 1,000 workers; transportation infrastructure, proxied by road length in kilometers per square meter of land area; and telecommunication infrastructure, proxied by internet access and the percentage of households with internet connectivity.

According to the African Development Bank Group (2018), infrastructure development is a key driver of progress and a critical enabler of productivity and sustainable economic growth. It contributes significantly to human development, poverty reduction, and the attainment of the Millennium Development Goals (MDGs). Investment in infrastructure accounts for more than half of the recent improvements in economic growth across Africa and still possesses the potential to contribute even more. Therefore, there is a need for adequate infrastructure such as secure energy systems, efficient transportation, reliable communication networks, resilient sanitation facilities, and affordable housing in order to enhance human capital development and productivity.

2) Human Development

The United Nations Development Programme (2023) describes human development as the process of enhancing people's capabilities, enlarging their choices, expanding their freedoms, and promoting human rights for all citizens. Human development emphasizes the freedoms people enjoy and what they are able to achieve and become. It is a concept of development that goes beyond economic growth by placing human well-being at the center of development efforts.

Understanding human development in its full complexity, identifying the barriers to its achievement, and formulating effective policy options require not only financial, political, and technical resources, but also intellectual investment. Nwokoye (2019) defines human development as the acquired abilities of individuals as productive agents resulting from exposure to education, training, good nutrition, shelter, safety, and healthcare services. Human development represents the combined intelligence, skills, knowledge, and expertise available within a nation. In other words, it encompasses the managerial, scientific, technical, and craftsmanship skills employed in creating, designing, developing, managing, and operating productive enterprises and economic institutions.

B. Theoretical Review

1) Human Capital Theory

The theory of human capital can be traced to macroeconomic development theory. In the 1950s, the major factors of production consisted mainly of land, physical capital, and management (Becker, 1993). However, by the 1960s, economists found it increasingly difficult to explain economic growth in the United States solely on the basis of these traditional factors of production. Consequently, scholars such as Schultz (1961), Becker (1964), and Mincer (1974) expanded the theory by emphasizing the importance of human capital.

Schultz (1961) viewed human capital as the capacity of individuals to adapt to changing environments. According to him, human capital becomes especially important in situations characterized by disequilibrium or rapid environmental change, where workers are required to adjust and adapt. He argued that the quality of the workforce is a crucial factor in facilitating the adoption of new and more productive technologies. In the contemporary era of sustainability and innovation, firms increasingly rely on employees as sources of creativity and innovation, encouraging them to develop new ideas and sustainable operational practices. Thus, human capital plays a pivotal role in helping organizations adapt to uncertain and changing environments.

In contrast, Spence's (1978) signaling model de-emphasized the role of education in directly increasing worker productivity. Instead, education was viewed primarily as a mechanism for signaling individual abilities and competencies to employers.

Relating this theory to the present study, individuals invest in themselves in order to adapt to changes within their environment and become more productive. Such investments in education, training, and skills acquisition ultimately improve labor productivity. However, investment in human capital can only be effectively achieved when adequate infrastructure is available to support economic and social activities.

2) Infrastructure-led Development Theory

The Infrastructure-led Development Theory was developed by Agenor (2006). The theory posits that constraints to economic growth and poverty reduction can be alleviated through increased public investment in infrastructure. Agenor argued that infrastructure services promote economic growth by reducing production costs, improving the productivity of private inputs, and increasing the rate of return on capital, especially in economies where infrastructure stock remains relatively low.

Furthermore, infrastructure can indirectly stimulate growth through several channels, particularly by improving health outcomes. Access to clean water and sanitation facilities enhances public health and increases productivity. Similarly, access to electricity improves hygiene, healthcare delivery, and overall living conditions.

This theory is relevant to the present study because it emphasizes that infrastructure significantly affects the health component of human capital development. Practically, access to electricity, clean water, sanitation, and other infrastructural facilities can improve overall human development. Infrastructure increases the economy's capacity to provide health and social services. Consequently, greater access to these services creates incentives for individuals to work, save, and invest in human capital development.

C. Review of Empirical Literature

Kusharjanto and Kim (2011) examined the relationship between infrastructure and human development in Indonesia using panel data covering the period from 2002 to 2005. The generalized method of moments (GMM) was employed as the estimation technique. The findings revealed that the proportion of households with electricity positively influenced human development, while other forms of infrastructure such as access to water, road networks, and the number of classrooms per student negatively affected human capital development.

Amador-Jimenez & Willis (2012) investigated the relationship between infrastructure and the Human Development Index (HDI) across various countries using Pearson correlation analysis. The study discovered that paved roads per capita exhibited the strongest correlation with HDI, whereas the quality of port infrastructure showed the weakest relationship.

Sapkota (2014) contributed to the literature on infrastructure access and human development using data from 91 developing countries between 1995 and 2010. Employing dynamic panel estimation through GMM, the study found that access to electricity and clean drinking water had positive and significant effects on the education and health dimensions of HDI. Additionally, road density positively influenced income levels.

Okinono et al. (2015) employed descriptive analysis to investigate the impact of infrastructure on human development in the Niger Delta region of Nigeria. Through purposive sampling, 284 respondents were selected from six communities. The findings indicated that infrastructural projects implemented by the Niger Delta Development Commission (NDDC) contributed positively to human capital development.

Nugroho (2015) examined the role of basic infrastructure in poverty alleviation in Indonesia using HDI as a proxy for human development. The study utilized panel data from 2000 to 2008 and adopted the fixed effect estimation method. The findings showed that roads, electricity transmission, healthcare centers, and schools had an inverse relationship with HDI in the study area.

Shuaibu and Popola (2016) investigated the roles of health, infrastructure, and institutions as determinants of human capital development in 33 African countries between 2000 and 2013. Using Sen's capability approach, the study revealed that all explanatory variables significantly influenced human capital development in the long run, although only institutional quality remained significant in the contemporaneous models.

Kristiyanto and Wuryaningrum (2017) examined the types of infrastructure influencing human development in Indonesia using fixed effect panel analysis covering 2011–2015. The findings showed that electricity positively influenced human development. Other variables such as bank credit exerted positive and significant effects, whereas income inequality, represented by the Gini ratio, negatively and insignificantly affected human development.

Nwokoye et al. (2020) employed the autoregressive distributed lag (ARDL) approach to investigate the drivers of human capital development in Nigeria between 1985 and 2017. The study found that expenditures on health and education, per capita income growth, and employment rates significantly enhanced human capital development, while inflation negatively affected it. Infrastructure development was found to positively but insignificantly influence human capital development.

Erasmus (2021) investigated the impact of public expenditure on human capital development in Nigeria using ordinary least squares (OLS) estimation with data spanning 1960–2019. The findings revealed that government investments in health and education positively and significantly affected HDI.

Nchofoung et al. (2021) utilized the GMM approach to analyze both the linear and non-linear effects of infrastructure on inclusive human development in Africa between 2003 and 2019. The study found that electricity, transportation, water, and sanitation infrastructures positively affected human development, whereas information and communication infrastructure had a negative and insignificant effect.

Acheampong et al. (2022) focused on the contributions of ICT and transportation infrastructure to human development in 79 countries using GMM estimation with data from 1990 to 2018. The study revealed that ICT and transportation infrastructure exerted varying effects on human development.

Osakede and Adeleke (2022) examined the effects of government borrowing and infrastructure on human development in Africa using panel threshold regression covering 1990–2019. The findings showed no threshold effect of infrastructure on human capital development among the 49 African countries included in the study.

Onikosi-Alliyu and Muhammed (2025) investigated the effect of digital infrastructure on HDI in Nigeria between 1986 and 2022 using the ARDL method. The findings showed that digital infrastructure exerted positive long-run effects on human development, although its short-run effects were negative.

Similarly, Ishizuka (2025) analyzed the impact of infrastructure on human well-being using long-term panel data from Japan between 1960 and 2020. Employing difference GMM estimation, the study found that transportation, water and sanitation, and educational infrastructure positively and significantly influenced HDI.

D. Gap in the Literature

The empirical literature reviewed indicates that most previous studies focused primarily on the effects of infrastructure variables such as electricity access, clean water supply, transportation networks, and ICT infrastructure on human capital development. However, limited attention has been given to the roles of population growth and tax revenue as important determinants of infrastructure development, particularly within developing economies such as Nigeria.

In countries experiencing rapid population growth, existing infrastructure often becomes insufficient to meet the increasing demands of the population. Likewise, tax revenue represents a major source of government funding for infrastructural development and maintenance. Therefore, the inclusion of population growth and tax revenue as control variables constitutes the major gap this study seeks to address in the existing literature.

3. RESEARCH METHOD

A. Theoretical Framework

This study is anchored on the Human Capital Theory developed by Schultz (1961). The theory emphasizes that individuals invest in themselves in order to adapt to changes in their environment and improve their productivity. Schultz identified five major categories of human capital development, namely health facilities and services, on-the-job training, formally organized education at the elementary, secondary, and tertiary levels, adult study programs outside firms, and migration of individuals and families in response to changing employment opportunities. According to Schultz, one of the most distinctive features of modern economic systems is the continuous growth and development of human capital.

The theory is relevant to this study because infrastructural development provides the enabling environment for individuals to acquire education, improve their health, access information, and develop productive skills. Therefore, improvements in infrastructure such as electricity, internet connectivity, water supply, and sanitation are expected to contribute positively to human capital development in Nigeria.

B. Model Specification

In line with the objectives and theoretical foundation of this study, an econometric model was developed to examine the impact of infrastructure on human capital development in Nigeria between 1999 and 2022. The study employed the Vector Error Correction Mechanism (VECM) as the estimation technique. Data were collected on Human Development Index (HDI), access to basic water and sanitation (ACW), access to internet (ACI), access to electricity (ACE), population growth (POG), and tax revenue (TXR).

Human Development Index (HDI) serves as the proxy for human capital development and represents the dependent variable, while ACW, ACI, ACE, POG, and TXR are the explanatory variables. The model of Kusharjanto and Kim (2011) was adopted and modified to suit the objectives of the present study. Population growth and tax revenue were introduced into the model because they are considered important determinants of infrastructural development, particularly in developing economies such as Nigeria.

The original model by Kusharjanto and Kim (2011) is specified as follows:

$$HDI = f(ELECT, WATER, ROAD, EDUC) \quad (1)$$

Where:

- ELECT = Share of households using electricity
- WATER = Access to water
- ROAD = Total road length
- EDUC = Number of classrooms per student

The modified functional model for this study is expressed as:

$$HDI = f(ACW, ACI, ACE, POG, TXR) \quad (2)$$

The stochastic form of the model is specified as:

$$HDI_t = \beta_0 + \beta_1 ACW_t + \beta_2 ACI_t + \beta_3 ACE_t + \beta_4 POG_t + \beta_5 TXR_t + \mu_t \quad (3)$$

Where:

- HDI = Human Development Index
- ACW = Access to Basic Water and Sanitation
- ACI = Access to Internet
- ACE = Access to Electricity
- POG = Population Growth
- TXR = Tax Revenue

- μ = Stochastic error term capturing other variables not included in the model
- β_0 = Constant term
- β_1–β_5 = Coefficients of the explanatory variables

The error correction model is specified as:

$$HDI_t = \beta_0 + \sum_{i=1}^{q} \beta_1 \Delta HDI_{t-1} + \sum_{i=1}^{q} \beta_2 \Delta ACW_{t-1} + \sum_{i=1}^{q} \beta_3 \Delta ACI_{t-1} + \sum_{i=1}^{q} \beta_4 \Delta ACE_{t-1} + \sum_{i=1}^{q} \beta_5 \Delta POG_{t-1} + \sum_{i=1}^{q} \beta_6 \Delta TXR_{t-1} + ECT_{t-1} + \mu_t$$

Where:

- Δ = First difference operator
- ECT_{t-1} = Error correction term representing the speed of adjustment from short-run disequilibrium to long-run equilibrium
- q = Optimal lag length

C. *Nature and Sources of Data*

This study utilized time series data covering the period from 1999 to 2022. Data were collected on Human Development Index (HDI), access to basic water and sanitation (ACW), access to internet (ACI), access to electricity (ACE), population growth (POG), and tax revenue (TXR). All data used in the study were sourced from the publications and statistical abstracts of the National Bureau of Statistics (NBS) and other relevant development indicators.

D. *Estimation Techniques and Procedures*

This study investigates the impact of infrastructure on human capital development in Nigeria using time series econometric techniques. To avoid spurious regression and ensure reliable estimates, the Augmented Dickey-Fuller (ADF) unit root test was employed to examine the stationarity properties of the variables. Since time series data are often characterized by non-stationarity, conducting the unit root test is necessary before model estimation.

Furthermore, the Johansen cointegration test was employed to determine whether a long-run equilibrium relationship exists among the variables included in the model. After establishing cointegration among the variables, the Vector Error Correction Mechanism (VECM) was adopted for estimation.

The VECM approach is considered appropriate because it captures both the short-run dynamics and long-run relationships among variables simultaneously. In addition, the technique measures the speed of adjustment from short-run disequilibrium to long-run equilibrium. The VECM also provides more efficient and consistent estimates for cointegrated time series variables, making it suitable for analyzing the relationship between infrastructure and human capital development in Nigeria.

4. RESULTS AND DISCUSSION

This section presents and interprets the empirical results obtained from the estimations carried out in the study for clearer understanding and analysis.

A. *Correlation Matrix*

The correlation matrix measures the degree of relationship among the variables included in the model. It is also used to determine whether multicollinearity exists among the explanatory variables.

Table 1. Summary of Correlation Matrix

Variables	HDI	ACW	ACE	ACI	POG	TXR
HDI	1.000000					
ACW	-0.270079	1.000000				
ACE	-0.722453	-0.079648	1.000000			
ACI	0.200931	0.136071	-0.362221	1.000000		
POG	0.681018	-0.081011	-0.302523	0.012230	1.000000	
TXR	-0.126778	-0.005803	0.323463	0.187617	-0.379623	1.000000

The correlation matrix presented in Table 1 indicates that all correlation coefficients are below the threshold value of 0.80. This suggests the absence of multicollinearity among the explanatory variables in the model. Therefore, the null hypothesis stating that there is no multicollinearity in the model is accepted.

B. *Descriptive Statistics*

Descriptive statistics present the mean, standard deviation, skewness, kurtosis, and Jarque-Bera statistics of the variables. These statistics help to explain the distribution, spread, and variability of the data.

Table 2. Summary of Descriptive Statistics

Statistics	HDI	ACW	ACI	ACE	POG	TXR
Mean	0.501650	1.791269	1.147653	1.726692	2.230781	3.863632
Median	0.502500	1.791686	1.243930	1.734799	2.229131	3.883820
Maximum	0.538000	1.903090	1.774517	1.779596	2.339531	4.099906
Minimum	0.450000	1.666518	0.000000	1.663701	2.120245	3.410794

Statistics	HDI	ACW	ACI	ACE	POG	TXR
Std. Dev.	0.027381	0.050967	0.518574	0.036639	0.069730	0.172693
Skewness	-0.190380	-0.398401	-0.900307	-0.209648	-0.005186	-0.917447
Kurtosis	1.800699	3.864601	3.144528	1.884103	1.728865	3.458948
Jarque-Bera	1.319417	1.152024	2.719250	1.184196	1.346576	2.981221
Probability	0.517002	0.562136	0.256757	0.553166	0.510029	0.225235
Sum	10.03300	35.82538	22.95305	34.53384	44.61562	77.27263
Sum Sq. Dev.	0.014245	0.049354	5.109463	0.025506	0.092382	0.566635
Observations	20	20	20	20	20	20

Table 2 shows that tax revenue (TXR) recorded the highest mean value of 3.863632 among all the variables. The standard deviation values for all variables are relatively low, indicating low variability within the data series. This suggests that the variables are closely distributed around their mean values, thereby making the estimates reliable for prediction and analysis.

The skewness statistics reveal that all variables are negatively skewed, implying the presence of longer left tails in their distributions. Furthermore, the kurtosis values indicate that HDI, ACE, and POG are platykurtic because their kurtosis values are below the benchmark value of 3. In contrast, ACW, ACI, and TXR exhibit kurtosis values around or above 3, indicating relatively normal peakedness.

The Jarque-Bera probability values for all variables are greater than the 5 percent significance level, implying that the variables are normally distributed. Therefore, the null hypothesis that the variables are normally distributed cannot be rejected.

C. Test of Stationarity

This subsection presents the results of the unit root test. Since time series data are often characterized by non-stationarity, the Augmented Dickey-Fuller (ADF) unit root test was employed to examine the stationarity properties of the variables. This test is necessary to avoid spurious or misleading regression results.

Table 3. Summary of the ADF Unit Root Test

Variables	ADF Statistics	Critical Value @5%	Order of Integration	Remarks
HDI	-6.1660	-3.0049	I(1)	Stationary
ACW	-6.0757	-3.0049	I(1)	Stationary
ACI	-3.8793	-3.0404	I(1)	Stationary
ACE	-6.4962	-3.0049	I(1)	Stationary
POG	-4.2902	-3.0049	I(1)	Stationary
TXR	-5.0171	-3.0049	I(1)	Stationary

The Augmented Dickey-Fuller (ADF) unit root test results presented in Table 3 indicate that all variables attained stationarity at first difference, that is, they are integrated of order one, I(1). The decision rule states that a variable is stationary when the absolute value of the ADF statistic is greater than the critical value at the 5 percent significance level. Since all variables satisfy this condition, the null hypothesis of non-stationarity is rejected.

D. Lag Selection Criteria

This subsection presents the results of the lag length selection criteria using the Vector Autoregression (VAR) selection approach.

Table 4. Summary of VAR Lag Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	224.9643	NA	3.94e-18	-23.04888	-22.75063	-22.99840
1	338.3727	143.2527*	1.42e-21*	-31.19712*	-29.10942*	-30.84380*

The result presented in Table 4 identifies lag one as the most appropriate lag length for the study. This decision is based on the Akaike Information Criterion (AIC), which recorded the lowest value among the selection criteria. According to the decision rule, the lag length associated with the lowest criterion value is selected. Therefore, lag one is considered the optimal lag length for the analysis.

E. Cointegration Test

Having established the stationarity properties of the variables, the next step was to examine whether a long-run equilibrium relationship exists among them. The Johansen cointegration test was employed for this purpose.

Table 5. Johansen Cointegration Result

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	Critical Value @5%	Max-Eigen Statistic	Critical Value @5%
None*	0.9582	156.79	95.754	69.825	40.078
At most 1*	0.8029	86.961	69.819	35.734	33.877
At most 2*	0.7007	51.227	47.856	26.541	27.584
At most 3	0.5379	24.686	29.797	16.981	21.132
At most 4	0.2926	7.7046	15.495	7.6144	14.265

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	Critical Value @5%	Max-Eigen Statistic	Critical Value @5%
At most 5	0.0041	0.0901	3.8415	0.0901	3.8415

The Johansen cointegration test results presented in Table 5 indicate the existence of long-run relationships among the variables included in the model. The trace statistics for "None," "At most 1," and "At most 2" are greater than their respective critical values at the 5 percent significance level. This implies the rejection of the null hypothesis of no cointegration at those levels.

The findings therefore confirm the existence of cointegrating equations among the variables, suggesting that a long-run equilibrium relationship exists between infrastructure variables and human capital development in Nigeria. Consequently, the use of the Vector Error Correction Mechanism (VECM) is appropriate for the analysis.

F. Vector Error Correction Model (VECM)

The Vector Error Correction Model (VECM) was employed to determine the joint dynamic behavior of the variables included in the model without imposing strict restrictions on the underlying structural parameters. The results of the VECM estimation are presented in Table 6.

Table 6. Summary of Vector Error Correction Model

Variables	Coefficient	Std. Error	t-Statistic	Prob.
CointEq1	-0.937568	0.292862	-3.201394	0.0019
D(HDI(-1))	0.197452	0.252454	0.782132	0.4363
D(ACW(-1))	0.000297	0.000246	1.206261	0.2311
D(ACE(-1))	-0.000106	0.000346	-0.306761	0.7598
D(ACI(-1))	0.003530	0.001590	2.220120	0.0291
D(POG(-1))	0.004294	0.002023	2.121999	0.0368
D(TXR(-1))	1.44E-06	7.87E-07	1.830104	0.0708
C	-0.024418	0.010672	-2.287952	0.0247

Statistics	Value	Statistics	Value
R-squared	0.540804	Mean dependent var	0.004318
Adjusted R-squared	0.311205	S.D. dependent var	0.006520
S.E. of regression	0.005411	Sum squared resid	0.000410
Durbin-Watson stat	2.143826		

The results presented in Table 6 explain the short-run dynamic behavior of the variables in the model. The coefficient of the lagged Human Development Index (HDI) is 0.197452, indicating that a 1 percent increase in the previous value of HDI will increase the current value of HDI by approximately 0.197 percent.

The coefficient of access to basic water and sanitation (ACW) is 0.000297, implying that a 1 percent increase in access to water and sanitation will increase HDI by approximately 0.0003 percent. Similarly, access to internet (ACI) has a positive coefficient of 0.003530, suggesting that a 1 percent increase in internet accessibility will increase HDI by about 0.0035 percent.

Population growth (POG) also exhibits a positive coefficient of 0.004294, indicating that a 1 percent increase in population growth will increase HDI by approximately 0.0043 percent. Tax revenue (TXR) equally shows a positive relationship with HDI, implying that increases in government revenue can contribute positively to human capital development through infrastructural investment.

However, access to electricity (ACE) has a negative coefficient of -0.000106, indicating an inverse relationship with HDI in the short run. This implies that a 1 percent increase in electricity access decreases HDI by approximately 0.0001 percent during the study period.

The error correction term (ECT) carries the expected negative sign and is statistically significant at the 5 percent significance level. The coefficient of -0.937568 indicates that approximately 94 percent of the disequilibrium from the previous period is corrected in the current period. This reflects a strong speed of adjustment from short-run disequilibrium to long-run equilibrium.

Based on the probability values, access to internet (ACI) and population growth (POG) are statistically significant because their p-values are less than 0.05. Therefore, the null hypotheses for these variables are rejected. Conversely, the lagged value of HDI, access to water and sanitation (ACW), access to electricity (ACE), and tax revenue (TXR) are statistically insignificant because their probability values exceed the 5 percent significance level. Hence, the null hypotheses for these variables are accepted.

The coefficient of determination (R^2) is 0.540804, indicating that approximately 54 percent of the variations in HDI are explained by ACW, ACI, ACE, POG, and TXR, while the remaining 46 percent is explained by other factors outside the model. The Durbin-Watson statistic of 2.143826 further indicates the absence of autocorrelation in the model.

G. Post-Estimation Diagnostic Tests

Diagnostic tests were conducted to examine the robustness and reliability of the estimated model. Specifically, serial correlation and heteroskedasticity tests were performed.

Null Hypothesis: No serial correlation at lag order *h*

Table 7. Summary of VEC Residual Serial Correlation LM Test

Lags	LM-Stat	Prob.
1	31.99371	0.6596

The serial correlation test result presented in Table 7 shows a probability value of 0.6596, which is greater than the 5 percent significance level. This implies that the model is free from serial correlation. Therefore, the null hypothesis of no serial correlation is accepted.

Table 8. Heteroskedasticity Test

Chi-Square	Df	Prob.
308.0000	294	0.2756

The heteroskedasticity test result in Table 8 shows a probability value of 0.2756, which is greater than 0.05. This indicates that the residuals are homoskedastic, meaning that the model is free from heteroskedasticity problems. Consequently, the null hypothesis of homoskedastic residuals is accepted.

H. Discussion of Findings

The findings of this study reveal that access to electricity exerts a negative effect on human capital development in Nigeria. This suggests that electricity access alone does not automatically translate into improvements in human capital development, particularly in terms of skills acquisition and productivity enhancement. Although electricity is expected to improve productivity, innovation, and investment, inadequate quality, instability in power supply, and poor infrastructure management may hinder its effectiveness in promoting human development. This finding does not conform to the a priori expectation. However, it partially aligns with the findings of Kusharjanto and Kim (2011), who also observed varying impacts of infrastructure variables on human development.

On the other hand, access to basic water and sanitation, access to internet, population growth, and tax revenue all exhibit positive relationships with human capital development. Access to clean water and sanitation improves public health conditions, reduces disease outbreaks, and minimizes healthcare expenditures that could otherwise reduce investment in education and self-development. This finding supports the study by Sapkota (2014), which established a positive relationship between access to water infrastructure and human development.

Similarly, access to internet positively influences human capital development. This implies that affordable and reliable internet connectivity improves access to information, education, communication, and digital opportunities, thereby contributing to the enhancement of human capital. The finding conforms to the a priori expectation and is consistent with the findings of Nchofoung et al. (2021).

Population growth also shows a positive and significant relationship with human capital development. This suggests that when population growth is effectively managed alongside proper utilization of available resources, it can expand the productive capacity of the economy through increased human capital formation. Likewise, tax revenue positively affects human capital development because government revenue serves as an important source of financing for infrastructural projects and public services that enhance human welfare and productivity.

Furthermore, the error correction term of approximately 94 percent indicates a rapid adjustment mechanism toward long-run equilibrium whenever disequilibrium occurs in the short run. The R^2 value of 0.540804 further indicates that the explanatory variables moderately explain variations in HDI, while the remaining proportion is attributable to factors outside the model.

5. CONCLUSION

This study examined the impact of infrastructure on human capital development in Nigeria, focusing on variables such as access to electricity, access to basic water and sanitation, access to internet, population growth, and tax revenue. The study covered the period from 1999 to 2022 due to data availability, while the Vector Error Correction Mechanism (VECM) was employed as the estimation technique.

The findings revealed that access to basic water and sanitation, access to internet, population growth, and tax revenue positively contribute to human capital development in Nigeria. These variables were found to play important roles in improving the welfare, productivity, and overall development of the population. Conversely, access to electricity was found to exert a negative effect on human capital development during the study period. This suggests that despite increased electricity access, challenges such as unstable power supply, poor infrastructure quality, and inefficiencies within the electricity sector may have limited its contribution to human capital formation.

Generally, the study established that infrastructural development remains a crucial factor in fostering economic growth and enhancing human capital development. Adequate infrastructure improves living conditions, expands opportunities for education and innovation, supports healthcare delivery, and promotes productivity. Therefore, infrastructure development is central to the sustainable development of human capital in Nigeria.

Based on the findings of the study, the following recommendations are proposed:

1. The government should improve water supply systems and sanitation facilities while ensuring that more citizens have access to clean water and hygienic environments. Public awareness on hygiene and sanitation practices should also be strengthened because these contribute positively to human capital development.
2. Since access to electricity was found to negatively affect human capital development, the government should focus on providing stable, reliable, affordable, and high-quality electricity supply capable of supporting productive and educational activities across the country.
3. The government should invest more in internet infrastructure, particularly in underserved and rural communities, to increase internet accessibility and digital inclusion. Greater internet access will encourage learning, innovation, and investment in human capital development.
4. Government should ensure effective monitoring of revenue generation and block all forms of revenue leakages. Improved tax revenue administration will increase government capacity to finance critical infrastructural projects that support human capital development.
5. Since population growth was found to positively influence human development, government should ensure efficient utilization and equitable distribution of available resources so that the growing population can benefit from infrastructural development and actively contribute to national productivity and development.

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